RESEARCH ON ROAD EDGES FOR LSS (LATERAL SUPPORT SYSTEM) DEVELOPMENT IN US AND EUROPE

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ABSTRACT

LSS (Lateral Support Systems) was developed as a driver support system to help prevent road departure crashes. It uses a forward monitoring camera to recognize the lane markings that identify lane boundaries. If there is a high probability of lane departure, LSS warns the driver and/or performs control to steer the vehicle back inside the lane. However, there are not always lane markings when road departures happen. Therefore, LSS systems that can detect road edges and help avoid departure from not just the lane but the road is more desirable. This research analyzes road edges existing in the US and Europe with the aim of understanding what road edges should be detected and avoided by LSS systems. Google Street View was mainly used for this analysis. The research found that grass is the most important road edge in both US and Europe. Also, other road edges such as curb, vertical boundary, and guardrail are found important for LSS systems. These results will help to design robust systems able to distinguish critical situations from non-critical situations and to establish valid evaluation methods for the new generation of LSS systems.

INTRODUCTION

Run-off-road crashes are a major crash type within the US vehicle crash population. The run-off-road crashes accounted for around 70% of the fatal single-vehicle crashes [1]. In Japan in 2013, single-vehicle crashes (such as rollovers and collisions with stationary objects or vehicles) and head-on collision crashes accounted for approximately 21% and 10% of fatal crashes, respectively [2]. A high proportion of these crashes occurred when the vehicle departed from the road. Reducing such road departure crashes is a major challenge in the development of technology to help achieve the ultimate desire of zero fatalities and injuries from traffic crashes.

The importance of reducing road departure crashes has also been recognized at a governmental level. For example, in 2011, the National Highway Traffic Safety Administration (NHTSA) in the US began assessments of lane departure warning (LDW) systems developed to help reduce these crashes [3]. Similar assessments have also been introduced in Europe and Japan [4][5].

In Japan, human factors such as drowsiness, distraction, and intoxication are involved in approximately 80% of road departure crashes (*Figure 1*) [6]. Furthermore, it was found that roughly 70% of drivers performed no steering or braking operations after departing the road in these crashes [6]. In the US, there was no driver maneuver before the departure in about 50% of road departure crashes [7]. These facts suggest that many road departure crashes occur without the driver realizing that the vehicle is departing from the lane.

LSS (Lateral Support Systems) was developed as a driver support system to help prevent road departure crashes. It uses a forward monitoring camera to recognize the lane markings that identify

lane boundaries. If there is a high probability of lane departure, LSS warns the driver and/or performs control to steer the vehicle back inside the lane. When in operation, this system is reported to be an effective way of helping to prevent road departure crashes [8].
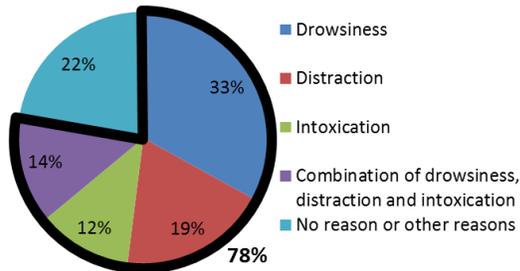

Figure 1.   Human factors of road departure crashes in Japan.

However, there are not always lane markings when road departures happen. The paper [7] describes that 91% of road departures happened on paved roads. Of those crashes, 86% of departures happened at non-intersection/interchange. Then, there were lane markings in 81.7% of those crashes. These facts suggest 64% of road departure crashes occurred on roads with lane markings, which means 36% of those occurred on roads without lane markings. Therefore, LSS systems that can detect road edges and help avoid departure from not just the lane but the road is more desirable.

This paper describes research on road edges existing in the US and Europe with the aim of understanding what road edges should be detected and avoided by LSS systems. These results will help to design robust systems able to distinguish critical situations from non-critical situations and to establish valid evaluation methods for the new generation of LSS.

A partnership between Toyota Motor Corporation, Toyota Motor North America, and TASI (Transportation Active Safety Institute) of IUPUI (Indiana University-Purdue University Indianapolis) was formed to conduct the US investigation. Also, a partnership between Toyota Motor Corporation and Applus IDIADA was formed to conduct Europe investigation.

METHODS

The investigation was conducted in the US and Europe. The detailed methods are explained in this section.

Methods Used for US Investigation

US investigation consists of three stages that are sampling, labelling and weighting of visual road images.

Firstly, sampling stage is explained. 824,957 random road locations, which are geographically equally distributed among all the US states including Hawaii and Alaska, were generated automatically. Those locations, however, are significantly biased in terms of road types because this distribution merely depends on geographical features of the US. Therefore, most of the locations are on low-level roads such as rural and local neighborhood roads. With the aim of having greater variations of road edge types, stratification sampling was utilized.

Three different constraints were used to generate all the divided groups. Three constraints are states, road level and population density level. State was selected as the first stratification variable because (1) different states may have different regulations and requirements for road infrastructures; (2) different states have different latitude, longitude and geographical attributes; and (3) different states may have different urbanization levels and road infrastructures.

Road level was selected as the second stratification variable because this is the most direct measure about the road in terms of materials, lane markings and other infrastructural features. The road levels were directly derived from TIGER (Topologically Integrated Geographic Encoding and Referencing data from United Stated Census – Geography). As many different road levels as possible were included unless the road level was not suitable for vehicle driving. Eight road levels were used, which are listed in Table 1.

Table 1.
Road levels used in the stratification plan

Code	Description
S1100	Primary Road
S1200	Secondary Road
S1400	Local Neighborhood Road, Rural Road, City Street
S1500	Vehicle Trail (4WD)
S1630	Ramp
S1640	Service Drive usually along a limited access highway
S1740	Private Road for service vehicles (logging, oil fields, ranches, etc.)
S1780	Parking Lot Road

Population density was selected as the third stratification variable in order to have more direct control of road-side objects and materials during the sampling process. Four population density levels were used: "less than 10", "10 to 50", "50 to 1,000" and "more than 1,000".

With the three stratification variables, the original dataset with 824,957 random road locations were separated into 1,600 groups (strata), with all the locations in the same group being from the same state, road level and population density level. The iterative sampling process was applied as illustrated in *Figure 2*. In each iteration, one location in each of the groups was randomly collected and removed, which was done from the first to the last group. When one group had no more locations left during the process, the group was skipped in the iterations afterwards. The iterations kept looping until enough locations were sampled.
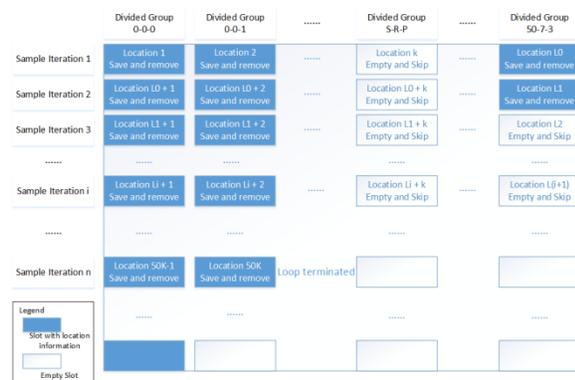
Figure 2. The iterative sampling for all strata.

After applying the stratified sampling process described above, a final dataset of 44,000 random road locations in the US was generated, as illustrated in *Figure 3*. The samples cover the whole US map from the deep inside mainland to all the corners including Hawaii and Alaska. In addition, the road locations are more concentrated in the metropolitans due to the stratification strategy.

Secondly, image labelling stage is explained. Out of 44,000 locations, Google Street View images were downloaded and manually labelled for 24,762 locations. *Figure 4* shows the example of the manual labelling process. Road edge type, on-road material, off-road material, season, weather, and so on were manually annotated by trained operators.

Thirdly, weighting stage is explained. Two weighting methods, mile percentages and car-mile percentages, were used.
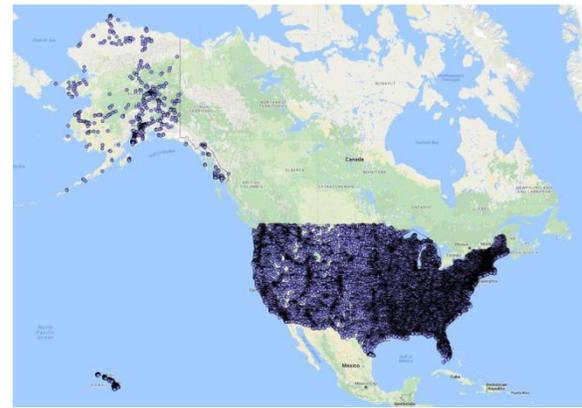
Figure 3. Distribution of the final stratified road locations in the US.
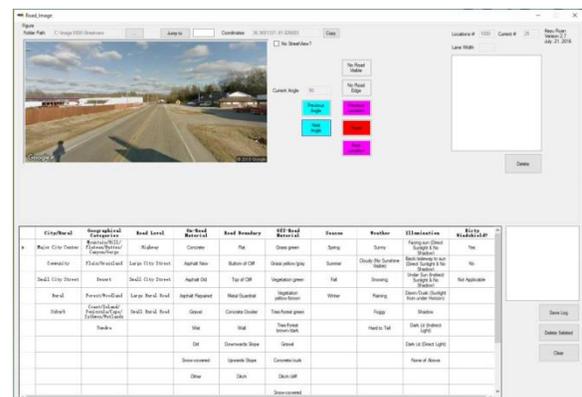
Figure 4. Example of manual data labelling for US investigation.

The mile percentage means how long the road edge type exists in terms of length of roads. 824,957 locations were geographically randomly sampled and classified into strata. Therefore, it was hypothesized that the number of each stratum was proportional to the road length of the stratum. After calculating the proportions of the strata, each location of 44,000 was weighted by this factor to calculate a mile percentage.

The car-mile percentage means how often the road edge type is encountered by vehicles. To calculate this, AADT (Annual Average Daily Traffic) was estimated. AADT for 19,074 locations were able to be calculated automatically from HPMS (Highway Performance Monitoring System). This automatic calculation, however, was able to be applied to only high level roads such as primary and secondary roads. For low level roads, the state map showing the traffic density

around a sampled location was opened in ArcGIS software and the AADT was manually estimated. It was quite a time-consuming process, so only 3,000 locations were processed. And the traffic densities of other locations were inferred from that of the similar road. After estimating AADT, the mile percentage of each location was transformed into the car-mile percentage by multiplying AADT.

Methods Used for Europe Investigation

Two methods were utilized to investigate road edges existing in Europe. The one is to sample 2,022 points from Google Maps and analyze them using Google Street View. The other is to drive the car with the camera installed and record videos. Later on, the recorded road edges were analyzed in detail.

Firstly, Google Street View analysis is explained. This method is aimed at finding the most common and representative road edges that can be found on European roads. With considering that the study can cover different types of roads through several countries and that the evaluation points would be randomly chosen, 60 different routes were defined through highways, main and rural environments, making a total of 20,881km of roads. At every 10km of each route, the corresponding Google Street View image was saved and afterwards analyzed. *Figure 5* shows the routes on the European map and Table 2 details the road network analyzed for each of the countries.

Figure 5. The 60 routes defined for Google Street View analysis in Europe.

Table 2.
Road network analyzed for Google Street View analysis

Country	Road network analyzed [km]
France	2,652
Spain	2,667
Sweden	2,393
Italy	1,432
Poland	1,175
UK	2,007
Hungary	669
Belgium	802
Netherlands	773
Czech Rep.	1,128
Greece	784
Norway	1,115
Romania	413
Denmark	1,010
Switzerland	695
Serbia	527
Bulgaria	443
Slovakia	70
Croatia	150

The analysis was conducted using the images obtained from Google Street View. The following points were investigated for each image: road type, right road shoulder's width, visibility of lane markings, road edge's clarity for camera recognition, right/left lane marking types, lane width, type of road edge, and curve radius. The road edge type was classified into curb, grass, wall, hill, snow, tree, soil, asphalt, guardrail and rigid barrier. *Figure 6* is the example of the analyzed scene.
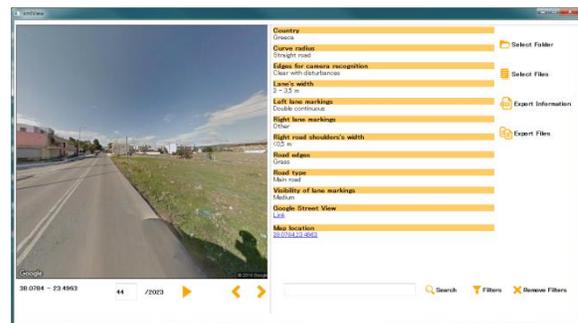
Figure 6. Example of road edge analysis for Europe investigation using Google Street View.

Secondly, the drive-and-record method is explained. This method is aimed at further analyzing road edge details. A regular vehicle was rented and equipped for some weeks with a

Video VBOX and 3 cameras. One camera was inside the vehicle on the windshield and pointing to the front. Another camera was placed on the right back door pointing to the right road shoulder. The third camera was on the left back door pointing to the left road markers. Also, an analogic trigger was mounted to make the later analysis easier.

The route went through 12 countries and took around 11,500km. The countries investigated were: Spain, France, Belgium, the Netherlands, Germany, Denmark, Sweden, Norway, Czech Republic, Austria, Italy and Switzerland. The driving started on February 3rd and ended on March 3rd, 2016. *Figure 7* shows the route on the European map.

Figure 7. The route used in drive-and-record method in Europe.

The analysis was conducted using the images recorded when the driver pressed the button. The driver pressed the button when he thought the scene was relevant to this research. The following points were investigated for each point: road type, right road shoulder's width, visibility of lane markings, road edge's clarity for camera recognition, right/left lane marking types, lane width, type of road edge, and curve radius. The road edge type was classified into curb, grass, wall, hill, snow, tree, soil, asphalt, guardrail and rigid barrier. *Figure 8* is the example of the analyzed scene.

Figure 8. Example of road edge analysis using drive-and-record method.

RESULTS

The results from the US and Europe investigation are explained in this section.

Results from US Investigation

Figure 9 shows the types of roads where road edges were extracted. This is based on 44,000 locations made by stratification sampling. It is understood that the road types are well balanced due to stratification sampling.
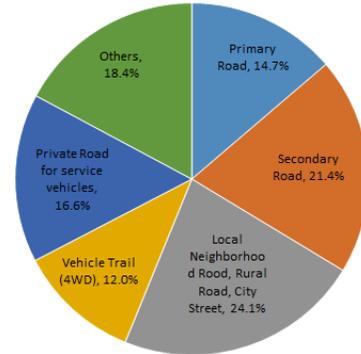
Figure 9. Types of roads from stratified samples in the US.

Figure 10 shows in mile percentages the types of roads where Google Street View images were analyzed. As described in the previous section, only 24,762 locations were used for this analysis. In general, Google Street View images can be obtained in urban or suburban areas. That is why, the road type "Local Neighborhood of Road, Rural Road, City Street" accounts for most of the miles, 73.8%. These 24,762 locations represent a total mile percentage of 36.82% out of 44,000 locations.

Figure 11 shows types of road edges from

Google Street View samples in mile percentages. The most common road edge type, which accounts for 55.5%, is grass. The second most common road edge type, which accounts for 25.2%, is curb. A combined total of these two accounts for 80.7%.
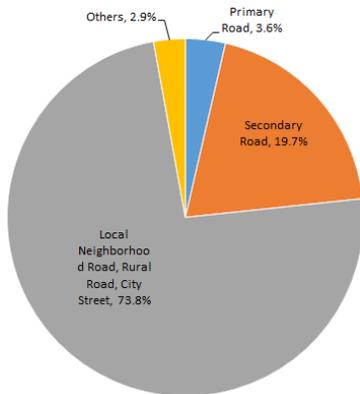

Figure 10.   *Types of roads from Google Street View samples in mile percentages in the US.*
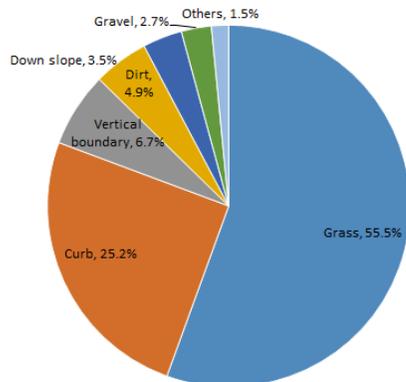
Figure 11.   *Types of road edges from Google Street View samples in mile percentages in the US.*

On the other hand, *Figure 12* shows in car-mile percentages the types of roads where Google Street View images were analyzed. The difference from the previous graph is that each location was weighted factoring in traffic density, AADT. This method substantially increased the proportions of primary and secondary roads. Since traffic is dense on high-level roads generally, this result is understandable.

Figure 13 shows types of road edges from Google Street View samples in car-mile percentages. The most common road edge type, which accounts for 48.8%, is grass. The second most common road edge type, which accounts for 22.2%, is vertical boundary. The third most common road edge, which accounts for 20.1%,

is curb. The traffic density significantly affects the vertical boundary such as concrete divider, wall and metal guardrail. The proportion of vertical boundary is increased from 6.7% to 22.2%. This might be because vertical boundaries are seen mainly on high traffic roads such as interstates roads.
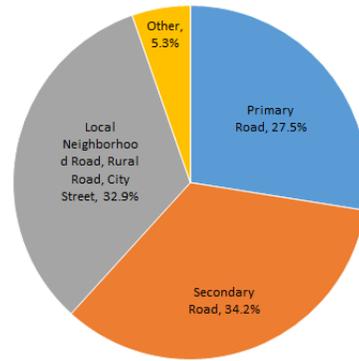
Figure 12.   *Types of roads from Google Street View samples in car-mile percentages in the US.*
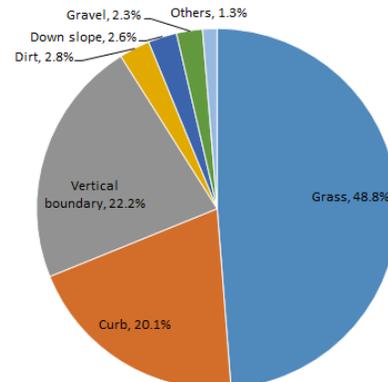
Figure 13.   *Types of road edges from Google Street View samples in car-mile percentages in the US.*

From *Figure 11* and *Figure 13*, it is understood that grass and curbs are the most important road edge types in the US that should be detected and avoided by LSS systems. Also, vertical boundaries might have to be taken into account. These results, however, are just based on Google Street View samples that can be obtained mainly in urban or suburban areas. Therefore, it should be considered that this result might not cover all the road conditions in the US.

Results from Europe Investigation
Firstly, the results from the Google Street View analysis are explained. *Figure 14* shows the types of roads where road edges were

extracted. The road type consists of 46.8% of highway, 45.4% of main road, 4.7% of rural road and 3.2% of urban road.

Figure 15 shows the types of road edges. The most common type of road edges, which accounts for 31.6%, is grass, and the second most common type of road edges, which accounts for 26.1%, is guardrails. From this result, it is understood that grass and guardrails are the most important road edges that should be detected and avoided by LSS systems. Another important point is that grass areas do not prevent vehicles from road departures. Therefore, grass might be the most important road edges for LSS systems.
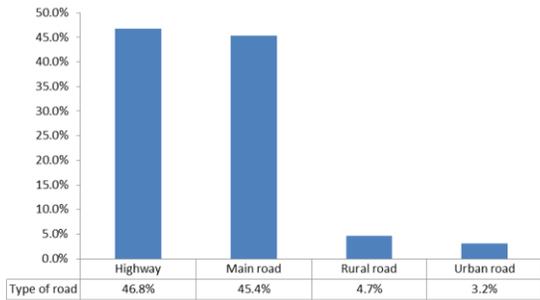
Figure 14.   Types of roads in Google Street View analysis in Europe.
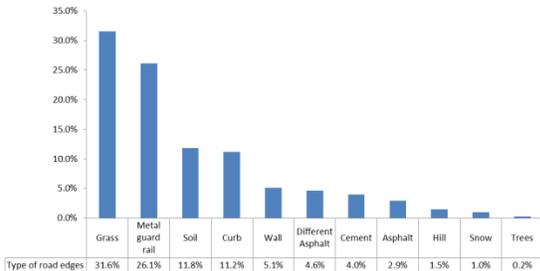
Figure 15.   Types of road edges in Google Street View analysis in Europe.

For further analysis, the proportion of grass to all the road edges was analyzed for each country. Romania, Croatia and Slovakia were excluded from this analysis because the numbers of their samples were too small to analyze. *Figure 16* shows the result, which explains that the Netherlands and the United Kingdom comprise over 50% of grass as the road edge, whereas countries such as Bulgaria, France, Italy, Norway, Spain and Switzerland relatively do not have a large proportion of grass.

On the other hand, *Figure 17* shows the proportion of guardrails as the road edges. Italy

and Spain comprise over 40% of guardrails as the road edge. Generally speaking, the countries that do not have a large proportion of grass have a large proportion of guardrails.
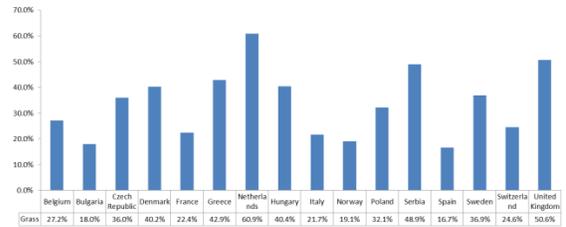

**Figure 16.   The proportion of grass as the road edge in Europe.**
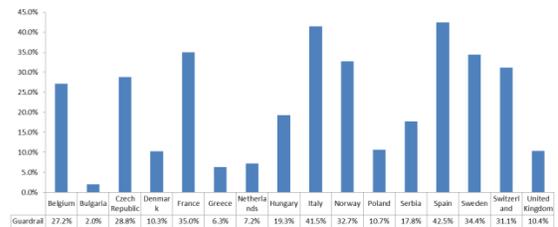
Figure 17.   The proportion of guardrails as the road edge in Europe.

Figure 18 shows a combined proportion of grass and guardrails to all the road edges in each country. Interesting finding is that most of the countries have over 50% of road edges as grass or guardrails. Hence, those two types should be prioritized for road edge detection of LSS systems.
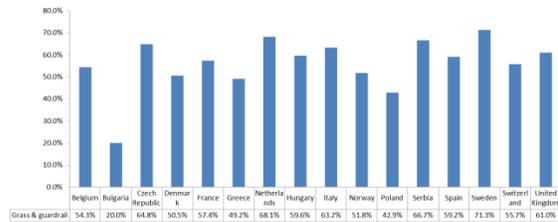

Figure 18.   The combined proportion of grass and guardrails as the road edge in Europe.

Figure 19 shows road edge's clarity, which is an important factor for camera recognition. 63.9% of the road edges are clear. From this result, it is understood that road edges on European roads mostly have clear edges. This result implies that LSS systems could cover most of the road edges on European roads if it can detect clear edges.

Secondly, the results from the drive-and-record method are explained. Since road edges were extracted at the timings when the driver

pressed the button, the next statistics is not referred to as the average road edges that are found on European roads. The aim of this activity is to analyze the details of road edges that can be found along the European roads.
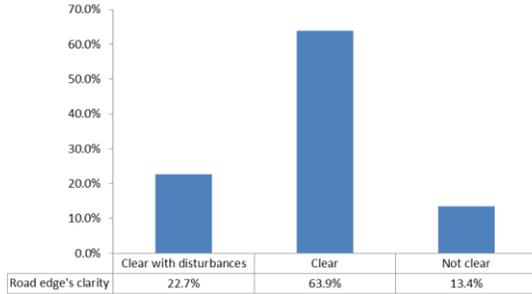

Figure 19.   Road edge's clarity in Google Street View analysis in Europe.

Figure 20 shows the types of roads where road edges were extracted. The road type consists of 50.56% of highway, 30.73% of main road and 18.71% of rural road.

Figure 20.   Types of roads in drive-and-record method in Europe.

Figure 21 shows the types of road edges. Guardrails and grass are main types of road edges that were found in this activity. The findings from this analysis are described below. Guardrails are the principal object used as road edges for highways. Sometimes, the vegetation, basically grass, is close to the guardrails. In tunnels and bridges, curbs and walls are the common road edges.

On main and rural roads, the main scenario is two-way roads consisting of narrow lanes. Guardrails are not very common, except for mountain roads or newly constructed roads.

Figure 22 shows road edge's clarity, which is an important factor for camera recognition. From this result, it is understood that road edges on European roads mostly have clear edges. For highways, the clarity of road edges

for camera recognition was mostly perceived as clear, except for cases where the light conditions were not favorable. On main and rural roads, the main road edge is vegetation; grass and bush might establish the road limits and this sometimes makes the road edge recognition difficult. In country like Sweden, snow and ice are also relevant road edge types. When the snow is dirty, it is difficult to determine where the limits of the roads are, as it has a black color similar to the road's color.
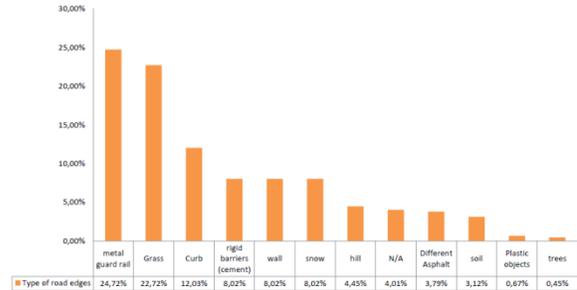

Figure 21.   Types of road edges in drive-and-record method in Europe.
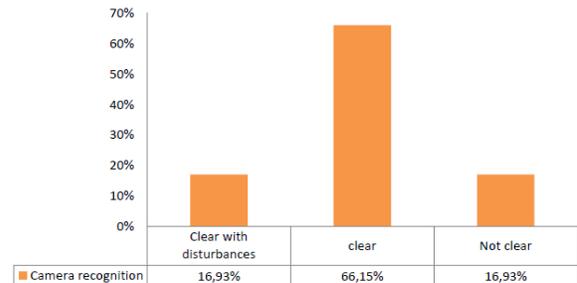

Figure 22.   Road edge's clarity in drive-and-record method in Europe.

From the aforementioned results, it seems there are two very different scenarios. The one is on highways wide and straight roads where the road edges are normally recognizable and the right road shoulder is wide. Also the visibility of road edges is good. The other is on rural roads narrow roads with vegetation on the sides with neither right line markers nor road shoulder. The two scenarios are found in all the countries.

CONCLUSION

In this paper, road edge types that should be detected and avoided by LSS systems are investigated and analyzed. In both US and Europe, grass is the most important road edge type. In addition, road edges that might have to

be taken into account are curbs, and vertical boundaries in the US, and guardrails in Europe.

Further analysis such as road edge characteristics for LSS sensors and road edges found in departure crashes might be interesting for future research. Also, establishing road edge test environments for LSS systems should be challenging yet important research.

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